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# Drift of Insecticidal Spray by Cold Air Drainage Winds in Western Mountains

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Under forest mountain conditions, insecticide sample sites were located below three 20-acre (8.1-ha) spray plots to sample drift carried out of the plots by cold air drainage winds. Samples of drift were collected on the ground and vertically upward for 200 ft (61 m). For all three plots, detectable deposits were recorded at the farthest sample site from the treated area, 2000 ft (610 m), 5000 ft (1524 m) and 7000 ft (2134 m). Droplet size and number of droplets per unit area usually decreased as the distance from the plots increased. Vertically, droplet size usually decreased as height increased but, in some instances, layering appeared to occur. The study demonstrated that cold air drainage winds carried large amounts of spray, sometimes equal to the amount that landed in the spray plots, out of the target area. Recommendations for minimizing or eliminating the problem are made.

*Retrieval Terms:* aerial spraying, insecticide drift, cold air drainage winds, forest insect control

Drift can be defined as "the movement of a portion of the air-borne particles of a dust or spray away from the intended point of application."[1] Although drift has been studied in agricultural spraying,[2 3] little has been done to document drift in forest spraying in mountainous terrain in Western North America. Studies on the movement and distribution of spray clouds in the forest canopy within a treated area have been done,[4 5] but these should not be confused with studies on drift.

The possibility of drift occurring during forest spraying appears to be considerably greater than in agricultural spraying. Spray plots in forests are usually located on sides of valleys or mountains and the spray is applied during the first few hours of daylight. With such conditions a meteorological phenomenon referred to by a number of names—cold air drainage,[6] mountain winds,[7] or downslope down-valley winds[5]—commonly occurs. At night and in early morning, cooler, heavier air from the mountains and ridge tops moves down the mountain or valley side. On reaching a valley floor, this cooler, heavier air usually turns down the valley. Generally, the winds are highest just above canopy level and they tend to follow closely the contours of the land, similar to the flow of a liquid. In speed they can range from a few hundred feet, to several miles per hour. Although researchers have speculated that such cold air drainage winds may carry spray out of plots,[8] I know of no tests to demonstrate that drift occurs, or to determine distances that spray can be carried and the quantity of spray carried.

In forest spraying, such winds would also carry insecticides from sprayed areas on mountain or valley sides to the valley floor where most of our sensitive areas—major fishing streams, human habitation, pastures, agricultural land and other—are located. In future years, drift may be even greater because of a proposal to use smaller spray droplets to increase target coverage and spray efficiency.[9] The smaller the spray droplet, the slower it will settle and the farther low velocity winds can carry it from the release point.[2]

To demonstrate that drift by cold air drainage winds was occurring, I planned this study to determine if spray deposit could be detected at various distances below three representative spray plots and to obtain some information on the physical make-up of the droplet in the spray cloud passing over the sample sites. Four to six sampling sites were set up at various intervals below each plot and a count of dyed spray droplets on Kromekote cards was used to assess

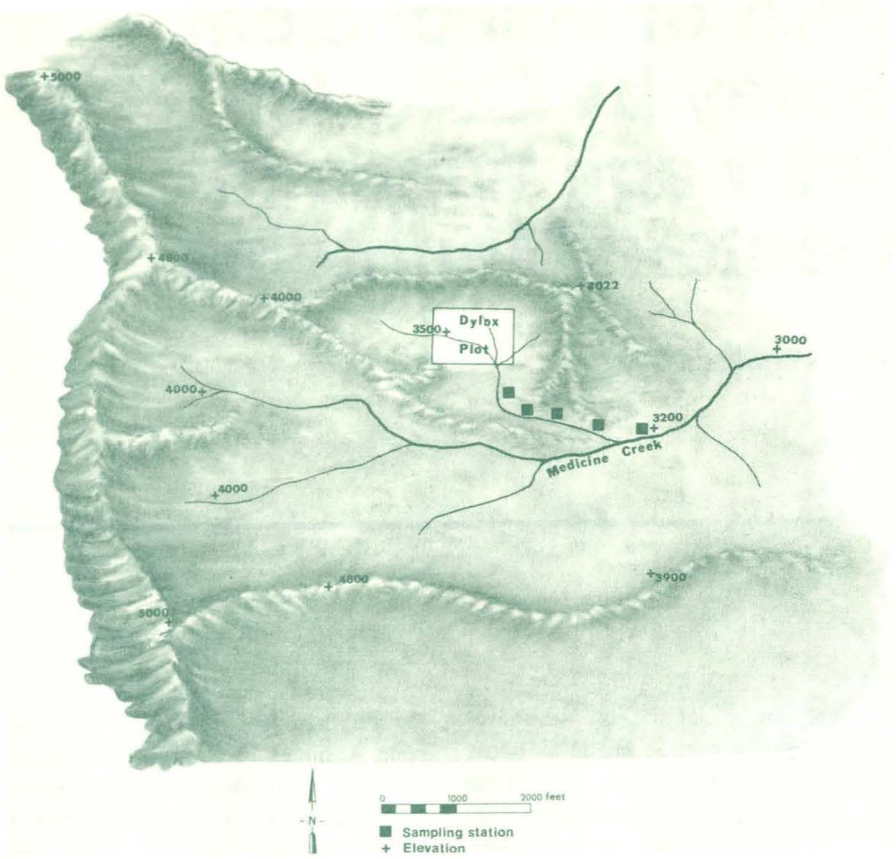


**Figure 1**—The Dylox treatment plot and spray deposit sampling sites were located in headwaters of Medicine Creek, a major tributary of Swauk Creek, in the Wenatchee National Forest, near Ellensbury, Washington.

drift. Sampling at each site was done both at ground level and at intervals of 10 ft (3 m) vertically to 200 ft (61 m). Two insecticides that have been used in western forest spraying—Orthene,[10] a water-based spray, and Dylox,[10] an oil-based spray, were used. Results of the study showed that cold air drainage winds carried large amounts of spray, sometimes equal to the amount that landed within the spray plots, outside the target area.

## STUDY SITE

The study area was located on the eastern slope of the Cascade Mountains, about 20 miles (33 km) northwest of Ellensburg, Washington. All plots and land used were part of the Wenatchee National Forest, and within the general drainage system of Swauk Creek.

The first plot was located in headwaters of Medicine Creek, a minor tributary to Swauk Creek, on the upper third of a mountainside near the crest of a spur ridge. The plot was in a fairly level basin but, at its lower end, the small creek draining the basin entered a narrow (less than 50-ft [15-m] wide) draw through which it ran for about 1000 ft (300 m) before joining the main valley of Medicine Creek (*fig. 1*). The bottoms of both the small side creek and Medicine Creek were heavily timbered with fir and spruce 50 and 80 ft (15 and 24 m) high. This plot was sprayed with Dylox.[10]

Two plots were located ½ mile (1 km) apart on the west side of Lion Gulch, a major tributary of Swauk Creek, but were separated from each other by a high spur ridge. These plots were on the lower half of a steep mountainside. Their lower edges were located from 200 to 300 ft (60 to 100 m) horizontally from the valley floor and 50 to 100 ft (15 to 30 m) above it (*fig. 2*). The valley below the plots was a typical flat-bottomed, mountain valley, 200 to 500 ft (60 to 150 m) wide, with a drop of 55 ft (16 m) per 1000 ft (300 m). The bottom contained scattered trees, open meadows, and large areas of willow brush. These plots were sprayed with Orthene.[10]

Each of the three plots was about 20 acres (8.1 ha) in size. Corners of the plots were located on the ground, then marked with color banners placed in a treetop to provide spray pilot guidance and orientation.

All spray sample sites were in open areas at least ½ acre (0.2 ha) in size at the bottom of the gulch or valley. Selection of sample sites was determined primarily by the presence of these openings.

## METHODS AND MATERIALS

Plots were sprayed on July 8, 9, and 10, 1975. Application of both formulations was by a Hiller 12E helicopter flying 50 ft (15 m) above canopy (top) at 45 mph (72 kph). Dylox was sprayed with 8 Bals Turbair spinning disc nozzles.[11] Orthene was applied with 23, 8002-flat-fan nozzles orientated forward and down for maximum breakup. Both formulations were applied at the rate of 1 gal per acre (9.3 *l*/ha). Dylox was applied in the undiluted form provided by the manufacturer, 1.5 lb a.i. per acre (1.67 kg a.i./ha). Orthene was mixed with water and applied at the rate of 1 lb a.i. per acre (1.12 *l*/ha). Rhodamine B dye (0.1%) was added to both formulations as a marking agent. The helicopter was loaded with 20 gal (76 *l*) of spray formulation and each plot was treated with parallel swaths 50 ft (15 m) apart. About 10 minutes were required to treat each plot.

Spray deposit was assessed by counting and measuring the diameters of the red spots formed by the spray droplets that had fallen on 4- by 5-inch (10 x 12.5 cm) Kromekote cards. For sampling at ground level, cards were placed in plastic holders on top of wire supports to hold the cards flat, horizontal, and above the general level of ground cover. Within each spray plot, 15 cards were randomly distributed in open areas. At each sample site located below the spray plots, 4 to 6 cards 10 to 30 ft (3 to 10 m) apart were placed in a line perpendicular to the valley floor.

Table 1 — *Meteorological conditions, measured on the ground, during spraying of plots, at first spray sampling site below each plot*

| Treatment | Time spray started | Temperature | | Relative humidity | Windspeed | |
|---|---|---|---|---|---|---|
| | *a.m.* | *°F* | *(°C)* | *Percent* | *ft/min* | *(m/min)* |
| Dylox | 5:05 | 62.5 | (17) | 65 | 68 | (20.7) |
| Orthene 1 | 5:45 | 57.0 | (14) | 89 | 110 | (33.6) |
| Orthene 2 | 6:25 | 59.0 | (15) | 67 | 85 | (25.9) |

the bottom of the valley to a depth of about 100 ft (30 m) (*fig. 4*).

Mean number of spots per $cm^2$ and VMD recovered from cards on the ground decreased with distance below the plot. For the vertical cylinders, except for low counts on the lower one or two cards, no distinct pattern of stratification in number of spots was observed. Also, VMD did not appear to decrease with height as it had in the first Orthene test, possibly indicating that the air mass carrying the spray cloud was more turbulent.

Cards placed at ground level indicated that 0.13 gal/acre (1.2 *l*/ha) of spray was recovered inside the plot, 0.22 gal/acre (2 *l*/ha) at 300 ft (90 m), 0.022 gal/acre (0.2 *l*/ha) at 1500 ft (450 m) and 0.011 gal/acre (0.1 *l*/ha) at 2500 ft (750 m) below the plot. On the basis of these recovery rates, it was estimated that 25 percent of the spray applied by the aircraft was recovered, 13 percent within the plot and 12 percent within 2500 ft (750 m) downwind.

## RECOMMENDATIONS

- Expect cold air drainage winds under most forest spraying conditions in western mountains, and consider such winds when planning treatment schedules and buffers outside test plots.
- Plan buffers with the full recognition that within 300 to 500 ft (90 to 150 m) on the downhill, downwind side of a plot, deposits on the ground can be as much as within the plot.
- New types of spray equipment may produce smaller droplets, which may be more effective for insect control, but remember the smaller the droplet, the more insecticide that will be lost as drift and the farther it may travel outside the

Table 2 — *Spray deposit recovered on Kromekote cards placed on the ground at various distances below three treated areas*

| Treatment and feet below plot | Cards/ site | Deposit[1] Drops/ $cm^2$ | Drop size (μm) | Volume (gal/acre) |
|---|---|---|---|---|
| Dylox: | | | | |
| Within plot | 15 | 14.01 | 214 | 0.16 |
| 300 | 6 | 22.50 ± 2.48 | 195 ± 14 | 0.108 ± 0.031 |
| 700 | 6 | 1.33 ± 0.36 | 113 ± 12 | 0.009 ± 0.007 |
| 1000 | 6 | 1.30 ± 0.92 | 60 ± 4 | 0.011 ± 0.005 |
| 1500 | 9 | 4.00 ± 0.45 | 50 ± 8 | 0.007 ± 0.009 |
| 2000 | 9 | 0.55 ± 0.24 | 18 ± 0 | <0.001 |
| Orthene 1: | | | | |
| Within plot | 15 | 16.01 | 187 | 0.204 |
| 500 | 5 | 5.55 ± 1.09 | 163 ± 6 | 0.069 ± 0.015 |
| 1000 | 5 | 3.13 ± 0.19 | 134 ± 9 | 0.030 ± 0.007 |
| 2000 | 5 | 1.71 ± 0.34 | 106 ± 6 | 0.011 ± 0.003 |
| 3000 | 5 | 0.63 ± 0.17 | 72 ± 8 | 0.003 ± 0.001 |
| 5000 | 5 | 0.70 ± 0.12 | 82 ± 4 | 0.004 ± 0.003 |
| Orthene 2: | | | | |
| Within plot | 15 | 16.40 | 218 | 0.130 |
| 300 | 5 | 7.67 ± 1.77 | 191 ± 11 | 0.220 ± 0.06 |
| 1500 | 5 | 4.64 ± 1.12 | 111 ± 9 | 0.022 ± 0.005 |
| 2500 | 5 | 2.12 ± 0.40 | 110 ± 4 | 0.011 ± 0.002 |
| 4000 | 5 | 1.07 ± 0.31 | 56 ± 2 | 0.003 ± 0.003 |
| 5000 | 5 | 0.78 ± 0.41 | 37 | <0.001 |
| 7000 | 5 | 0.39 ± 0.28 | <30 | <0.001 |

[1] Mean ± standard error (S.E.).

Table 3 — *Average spray deposit recovered from each 200-ft vertical line of paper cylinders placed at various distances below three treated plots*

| Treatment and feet below plot | Deposit Drops/$cm^2$ Mean ± S.E. | Drops/$cm^2$ Range | Drop size (μm) Mean ± S.E. | Drop size (μm) Range |
|---|---|---|---|---|
| Dylox: | | | | |
| 300 | 31.6 ± 5.6 | 10.7 to 101 | 70 ± 5.3 | 37 to 112 |
| 700 | 41.7 ± 9.4 | 4.0 to 134.0 | 60 ± 2.9 | 42 to 91 |
| 1500 | 82.7 ± 17.4 | 1.7 to 137.7 | 51 ± 5.0 | 36 to 120 |
| 2000 | 5.3 ± 1.3 | 0.0 to 12.7 | 27 ± 3.7 | 15 to 58 |
| Orthene 1: | | | | |
| 500 | 35.9 ± 5.6 | 8.1 to 81.3 | 123 ± 3.8 | 98 to 146 |
| 1000 | 11.6 ± 1.1 | 2.5 to 21.7 | 120 ± 4.1 | 88 to 148 |
| 2000 | 3.2 ± 0.5 | 0.4 to 7.6 | 92 ± 3.4 | 72 to 137 |
| 3000 | 0.11 ± 0.03 | 0.0 to 0.27 | 68 ± 6.7 | 40 to 127 |
| 5000 | 1.14 ± 0.46 | 0.0 to 8.08 | 68 ± 4.8 | 50 to 96 |
| Orthene 2: | | | | |
| 300 | 56.3 ± 6.2 | 18.7 to 106.1 | 152 ± 4.2 | 124 to 185 |
| 1500 | 6.8 ± 1.0 | 0.4 to 13.1 | 111 ± 3.7 | 88 to 138 |
| 2500 | 4.6 ± 1.2 | 0.1 to 17.2 | 97.2 ± 6.8 | 40 to 146 |
| 4000 | 3.2 ± 0.8 | 0.1 to 13.6 | 81.4 ± 7.5 | 33 to 118 |
| 5000 | 0.22 ± 0.05 | 0.02 to 1.01 | 62.5 ± 8.3 | 28 to 127 |
| 7000 | 0.45 ± 0.13 | 0.01 to 2.02 | 78.4 ± 10.0 | 40 to 123 |

**Figure 4**—The smoke cloud moved down the valley after spraying of the Orthene 2 plot.

aircraft was recovered at ground level within the plot (*table 2*). Almost as much spray was recovered 300 ft (100 m) below the plot (0.11 gal/acre [1.04 *l*/ha]), but at 700 ft (213 m) the amount recovered had declined to 0.009 gal/acre (1.7 *l*/ha) (*table 2*). It was estimated from these data that only 21.5 percent of the spray applied was recovered on the ground, 16 percent within the plot and 5.5 percent outside. The remaining spray was either intercepted in the forest canopy, lost by evaporation, or carried as drift outside the area being studied.

Mean drop size at each of the sampling sites below the plot showed a decrease in VMD at sequential distances (*table 3*). What was unexpected, however, was an increase in the number of spots per $cm^2$ recovered on the vertical cards at 1500 ft (500 m). An examination of the topography below the plot offers a possible explanation (*fig. 1*). The plot lay in a large level basin, but the creek draining it passed through a narrow, steep-sided gorge. Apparently, cold air drainage winds flowing out of the basin behaved like a liquid. On entering the narrow gorge the spray cloud became narrower and moved at a faster rate, thereby increasing the number of droplets impinging on the suspended cylinders (*table 3*). By the time the cloud had reached the last sample site (2000 ft [600 m]), the small side gulch had joined the larger main valley of Medicine Creek, allowing the spray cloud to spread out and slow down.

In passing through the narrow side gulch at the 1500-ft (450-m) sample site, the spray cloud also provided an interesting vertical cross section. Number of spots per $cm^2$ impinging on the cards below 50 ft (15 m) was very low. They increased to a maximum between 80 and 150 ft (25 and 45 m) and then decreased above that. These concentrations could be interpreted as indicating that most of the spray cloud passing through the narrow gulch moved as a narrow layer just above the treetops.

## Orthene 1

Below the Dylox plot, spray deposit was found at all five sample sites including the farthest, 2000 ft (600 m) below the plot. The farthest of the five sample sites for the next plot (Orthene 1), therefore, was moved to 5000 ft (1500 m) down the valley. Again, deposit was recorded at all sampling sites, so for the final test (Orthene 2), six sample sites were used with the farthest 7000 ft (2130 m) below the plot.

Topography of the valley below the two Orthene plots was different from the Dylox plot, with a wider, flat-bottomed open valley of fairly uniform width and gradual slope (*fig. 2*). Smoke first moved down the valley slope toward the valley floor. As it approached the valley floor it began to shift and flow down-valley. At 500 ft (150 m) below the plot, the smoke cloud was entirely above the valley floor and moving directly down the valley. Spray deposits were recovered from both ground cards and vertical cylinders at all study sites, including the farthest from the spray plot at 5000 ft (1500 m).

Cards placed out on the ground showed that only 0.204 gal/acre (1.9 *l*/ha) of the spray was recovered within the plot, 0.069 gal/acre (0.65 *l*/ha) at 500 ft below the plot, 0.03 gal/acre (0.28 *l*/ha) at 1000 ft (300 m), and 0.011 gal/acre (10.3 *l*/ha) at 2000 ft (600 m) (*table 2*). On the basis of these data it was estimated that 27.8 percent of the spray applied was recovered on the ground, 20.0 percent within the plot, and 7.8 percent within the first 2000 ft (600 m), downwind of the plot.

Vertically, no distinct stratification in number of droplets per $cm^2$ was observed. Spots per $cm^2$ and VMD decreased on both vertical cylinders and ground cards at each sample site below the plot, except for a slight increase at the last sampling site (*table 3*). Spots per $cm^2$ on the vertical cylinders did not appear to show any observable stratification, except on the vertical line at 5000 ft (1500 m), where a definite concentration was observed from 170 to 200 ft (51 to 60 m). On most of the vertical lines (with the exception of the one at 5000 ft [1500 m]), drop size decreased with height. This was expected because the larger drops settled out first, producing a decrease in mean spray droplet size as the spray cloud moved down the valley.

## Orthene 2

The second Orthene test was done in the same valley as the first, although the plot was located ¼ mile (½ km) farther up the valley and separated from the first plot by a high spur ridge. The smoke cloud released during spray again first drifted downslope toward the valley floor, then shifted to move down the valley. At 1500 ft (450 m), the smoke cloud covered

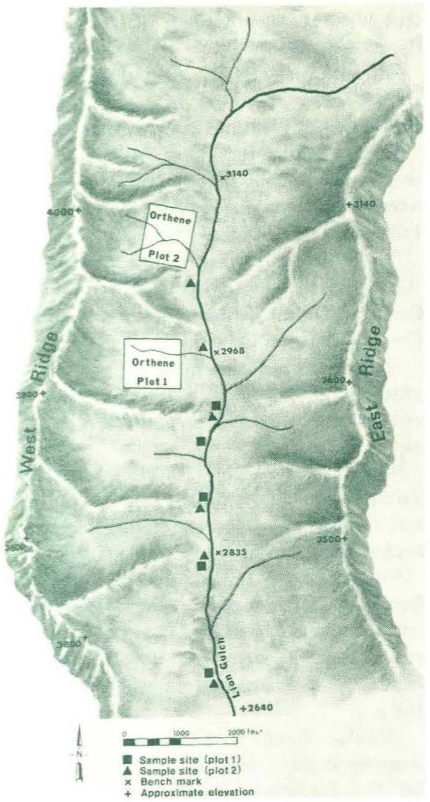


**Figure 2**—The Orthene spray plots and spray deposit sampling sites were located on the west side of Lion Gulch, a major tributary of Swauk Creek in the Wenatchee National Forest, near Ellensburg, Washington.

For vertical sampling, the Kromekote cards were rolled into cylinders 4 inches high and 1.6 inches in diameter and suspended at 11-ft (3.3-m) intervals from a line supported by several helium-filled meteorological balloons (*fig. 3*). Because the balloons usually drifted downwind at an angle of 30° from vertical, actual vertical height of the cylinders was at 10-ft (3-m) increments above the ground. Because variations in windspeed sometimes deflected the vertical line more or less than 30°, height of the cylinders above the ground was considered to be approximate.

No direct correlation was drawn between the deposit on cylinders and the flat cards on the ground. Spray deposit of cards placed on the ground was assessed in three areas randomly selected from the upper surface of each card, and represented droplets that impinged on the card while falling vertically. By contrast, the three areas used on each cylinder were all from the surface that faced the wind. The deposit on a cylinder is directly related to the wind velocity carrying the spray droplets.[13]

The deposit cards were in place at least ½ hour before spraying and left out 1 hour after spraying, or until the spray cloud had passed the sampling site.

Direction and speed of air mass movements at ground level were determined by igniting a small smoke bomb, and determining the length of time required for a puff of smoke to move a predetermined distance. The progress of the large smoke cloud could be visually followed as it moved down the valley (*fig. 4*).

In the Orthene tests, an electronic scanning device, Quantimat 720, automatically counted and sized the spots formed on the cards by the dyed spray droplets.[12] On each ground card three randomly selected areas of 0.66 $cm^2$ were read. Three areas of similar size were read from the cards used to make the cylinders, but on these, the spots were selected along a line down the surface of the cylinder which had faced into the wind and on which the spray had impinged. Each card was analyzed for average number of spots per $cm^2$, and average size of spots expressed as the volume-median diameter, VMD. For ground cards estimated volume of spray recovered was also determined in gallons per acre.

In the Dylox tests, two problems occurred. One vertical line of the cylinders for Dylox at 1000 ft was lost when too small an opening was chosen for the sample site and the line became tangled in a tree. Also, the Dylox plot was on a southeast facing exposure and several of the vertical lines of cylinders received early morning sunlight that caused fading of the dyed spots on the cards. Because of non-uniformity of spots, these cards could not be read accurately with the Quantimat and instead were counted with a microscope and a UV light source.

It was assumed that the spray cloud, moving down the valley away from the spray plots, would not expand to a width greater than the width of the valley. It was possible, therefore, to use the gallons per acre figure (recovered at ground level at the sampling site below the plot) and the width of the valley to estimate the total amount of material reaching the ground outside the spray plot.

Although mathematical estimates were made of droplets, size, abundance, and volume recovered at the various sampling sites, tests were not replicated. I did not consider it feasible, therefore, to do detailed statistical analysis of the data, and any inferences based on the results can only be considered as tentative.

Temperature, relative humidity and windspeed were measured on the ground at time of spray (*table 1*). Smoke bombs ignited before and after spraying indicated that cold air drainage winds occurred in all three plots and continued for at least 1 to 2 hours after spraying. Twenty-two plots of similar size were sprayed in the Swauk drainage system that spring with chemical insecticides, as part of another experiment.[14] Cold air drainage winds were recorded in 19 of the plots indicating that such a condition is not unusual.

## RESULTS AND DISCUSSION

### Dylox Plot

Only 16 percent (0.16 gal/acre [1.1 l/ha]) of the Dylox spray released by the

**Figure 3**—Lines of 20 cylinders, about 10 ft (3 m) apart were used to sample the passing spray cloud at each drift sampling site. A line of cylinders was made from Kromekote cards, suspended below two meteorological balloons.

treated plots.

• Spray as late in the morning as possible when spraying must be done near a sensitive area. If the timing is correct, the morning warming can break the inversion and destroy the cold air drainage before it has had a chance to carry the drift to the sensitive area.

• Do not assume that cold air drainage winds do not exist, but use smoke or fine dust to look for them. Cold air drainage winds, because of their low velocity, are sometimes difficult to spot. Most wind measuring equipment, such as the pity ball gages supplied in fire weather kits, are not sensitive to winds less than 2 miles (3.2 km) per hour.


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